POTENTIAL PEAK LOAD REDUCTIONS FROM RESIDENTIAL ENERGY EFFICIENT UPGRADES

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ABSTRACT

The demand for electricity is continuing to grow at a substantial rate. Utilities are interested in managing this growth's peak demand for a number of reasons including: costly construction of new generation capacity can be deferred; the reliability of the distribution network can be improved; and added environmental pollution can be minimized. Energy efficiency improvements, especially through residential programs, are increasingly being used to mitigate this rise in peak demand. This paper examines the potential peak load reductions from residential energy efficiency upgrades in hot and humid climates. First, a baseline scenario is established. Then, the demand and consumption impacts of individual upgrade measures are assessed. Several of these upgrades are then combined into a package to assess the synergistic demand and energy impacts. A sensitivity analysis is then performed to assess the impacts of housing characteristics on estimated demand and energy savings. Finally, the demand, energy, and environmental impacts are estimated at the community level.

INTRODUCTION

Approximately 1.5 million new homes are constructed each year in the United States according to the U.S. Census Bureau. This construction is fueling a demand for electricity that the Energy Information Administration (EIA) projects will grow by 22 percent nationally between 2000 and 2020 (equivalent to about 1% annual growth on average). Utilities and planners are interested in managing the peak demand associated with this growth for a number of reasons including: costly construction of new generation capacity can be deferred; the reliability of the distribution network can be improved (less strain on the feeder lines and substations); and added environmental pollution can be minimized. Energy efficiency improvements, especially through residential programs, are increasingly being used to mitigate this rise in peak demand.

While some studies have tried to quantify the demand savings associated with energy efficiency upgrades, the relationship is not well understood. This relationship is further complicated by the synergistic effect of bundling individual upgrades into energy efficiency packages. In addition, the size of the demand impact is affected not only by the upgrades themselves, but also by the home's characteristics (e.g., house size, window area, foundation type, etc.) Since these characteristics can vary significantly from house to house, it has been difficult to assess the demand reduction potential of energy efficiency upgrades at the program level.

The purpose of this paper is to improve the understanding of the relationship between energy efficiency upgrades and the potential impact they have on reducing the peak demand in new homes. An analysis was conducted using the DOE2.1E computer-modeling program[1]. The methodology and results of this analysis are presented and conclusions and next steps are identified. The results give utilities, building science professionals, and planning officials a better understanding of how residential energy efficiency programs can be used to help mitigate the rising demand for electricity.

METHODOLOGY AND RESULTS

This analysis was conducted using the DOE2.1E energy modeling program and was limited to one hot and humid city – Houston, TX. The homes in this analysis use natural gas for space heating and domestic water heating. While many of the upgrades analyzed in this paper will have an impact on gas consumption (e.g., windows, envelope insulation), this paper is focused strictly on the demand and consumption impacts of electricity used for cooling and ventilating homes. This analysis also excludes the potential impacts that efficient lighting or appliances may have.

[1] DOE-2.1e-121 (proprietary version from Hirsch & Associates)

There are two important factors that influence the peak demand results from this analysis. The first factor is the way in which peak demand is calculated within the DOE-2 computer program. DOE-2 reports electric demand (kW) for one-hour intervals. This means that during any one-hour period, the actual demand may fluctuate in each 15 minute interval, but DOE-2 will report only the *average* kW for the hour. This method can cause short-term 15-minute spikes to be flattened. However, for large population of homes, average one-hour peaks are more indicative of the peak demand from a "typical" home within a large group of homes, rather than the 15-minute peak demand from a unique home. The second factor is the use of Typical Meteorological Year (TMY2) weather data. This weather data is based on 30 years of real-world data and represents the "typical" weather experienced in a particular city. It therefore does not necessarily capture the more dramatic, real-world weather fluctuations that may occur in a given year. Other studies have examined the variability between real-world weather and TMY2 data sets and found that the use of TMY2 data is good for predicting long-term average energy consumption and demand. Thus the results of this analysis indicate the average demand impacts for a typical home over a long time frame.

This analysis was divided into five distinct steps. The first step was to develop a base case scenario. The second step was to identify and analyze upgrade options for the base case scenario. The third step was to assess the synergistic impact of combining selected upgrades into an energy efficiency package. The fourth step was to conduct a sensitivity analysis of the base case and upgrade package in order to evaluate the impact of different building characteristics on peak demand and electricity consumption. The fifth step was to evaluate the impacts this upgrade package could have at a community level if it were implemented as part of a residential energy efficiency program. The methodology and results of each of these steps is presented below.

Step 1: Develop Base Case Scenario

The first step in this analysis was to develop a base case scenario from which the energy efficiency impacts could be assessed. Defining these characteristics is important because they directly impact the energy and demand savings attributable to the energy efficiency upgrades. For example, a home with a large area of west-facing windows will have a greater cooling load than an identical home with less west-facing glazing. Therefore, the energy and demand savings from a window upgrade will not be the same for these two homes. In order to remove this dependence on a given set of house characteristics, a number of prototypical base case homes were developed. These base case homes were developed through a two-step process. First, variations were identified for some of the key characteristics of a home. Next, base case homes that incorporated these variations were designed to meet the 2000 International Energy Conservation Code (IECC). This energy code was chosen for this study since it was recently adopted as the state code in Texas[2]. Exhibit 1 shows the home characteristics, and variations, that comprise the base case scenarios.

[2] Texas adopted the International Residential Code (IRC) as it existed on May 1, 2001. This is the IRC 2000, amended by the 2001 Supplement.

Exhibit 1. Home Characteristics of the Base Case Scenarios

Home Characteristic	Variations Modeled
Area per floor (square feet)	1250, 1750, 2500
Number of stories	single, double
Foundation type	crawl space (vented, 5 nac/h) slab-on-grade
Aspect ratio	2:1
House orientation	North, East, South, West
Percent glazing (window to floor area)	15%, 18%, 21%
Window U-value	0.47
Window SHGC	0.40
Window distribution	50.0% front, 25.0% back, 12.5% per side
External shading (e.g., overhangs)	None
Floor insulation (above unconditioned space)	R-11
Wall insulation	R-11
Attic insulation	R-22
Roof solar absorptivity	0.35 solar abs., 0.75 solar abs., 0.90 solar abs.
Infiltration (nac/h)	0.46
Air conditioner efficiency	10 SEER
Gas furnace efficiency	78 AFUE
Thermostat	Programmable w/ 6 degree setup/setback
Duct air loss	6%
Duct insulation[3]	R-6
Floor-weight	11.5 pounds per sq. ft
Shading	90% in winter months, 70% in summer months
Internal loads (from lights, people, equipment)	3,600 Btu per hour
Garage	Not modeled

By varying each of the possible combinations in Exhibit 1, 432 unique base case scenarios were created. Each of these scenarios was then modeled in DOE-2 to estimate peak demand and electrical consumption for the base cases. Instead of using the simple average for the results, a weighted average was calculated based on the distribution of new construction home size in southeast Texas. This distribution, and the home configurations modeled to represent them, is shown in Exhibit 2. This weighting is used throughout the paper unless otherwise noted.

Exhibit 2. Distribution of New Homes Sizes in Southeast Texas and Configuration Modeled

Square Foot of Homes	% of Total Homes	Configuration Modeled
< 1500 ft^2	4	Single story (1250 total ft^2)
1,500-1,999 ft^2	23	Single story (1750 total ft^2)
2,000-2,999 ft^2	39	Single story (2500 total ft^2), Double story (2500 total ft^2)
3,000-3,999 ft^2	20	Double story (3500 total ft^2)
> 4,000 ft^2	14	Double story (5000 total ft^2)

Source: Nexus Market Research

The weighted average peak demand for the 432 base cases was 5.3 kW and the weighted average annual electrical consumption was 6,090 kWh. There was substantial variation in the average peak demand for the base cases and it was largely due to the size of the home. The average peak demand for 1,250 square foot homes was 2.76 kW while it was 8.79 kW for 5,000 square foot homes. The average peak demand, by size of home, can be found in Exhibit 7.

Step 2: Identify and Analyze Individual Upgrades

Once the base case scenarios were developed, energy efficiency upgrades were identified that were appropriate for the Houston market. The upgrades generally were either improvements to the thermal envelope or to the HVAC equipment. While it is possible to reduce a home's peak demand through lighting and appliance upgrades, these were not considered in this analysis. The energy efficiency upgrades that were selected for modeling are presented in Exhibit 3.

[3] The ducts are located in the attic, not in conditioned space.

Exhibit 3. Individual Energy Efficiency Upgrades

Upgrade Type	Base Case	Upgrade Options
Thermal Envelope	Wall insulation: R-11	R-13
		R-15
	Attic insulation: R-22	R-30
	Air infiltration: 0.46 nac/h	0.35 nac/h
Windows	0.47 U-Value 0.40 SHGC	0.35 U-value
		0.30 SHGC
		0.35 U-value and 0.35 SHGC
		0.30 U-value and 0.30 SHGC
HVAC System	Air conditioner: 10 SEER	11 SEER
		12 SEER
		13 SEER
		14 SEER

For each of the 432 base case scenarios identified in Step 1, every energy efficiency upgrade was modeled in DOE-2. For each upgrade analyzed, only the upgraded specification was modified - the other home characteristics were not changed. Altogether, over 6,000 homes were modeled using DOE-2. The results were averaged together by upgrade, enabling an assessment of the demand and energy savings attributed to each upgrade across the various base case scenarios. These results are presented in Exhibit 4.

Exhibit 4. Average Peak Demand and Electricity Consumption of Base Case and Upgrade Scenarios

Energy Efficiency Upgrade	Peak Demand (kW)			Electricity Consumption (kWh/year)		
	Average	Average Savings from Base Case		Average	Average Savings from Base Case	
Base case	5.32	-		6,090	-	
Wall insulation: R-13	5.26	0.06	(1%)	6,024	66	(1%)
Wall insulation: R-15	5.21	0.11	(2%)	5,966	124	(2%)
Attic insulation: R-30	5.30	0.02	(0.4%)	6,058	32	(0.5%)
Infiltration: 0.35 nac/h	4.97	0.35	(7%)	5,828	262	(4%)
Window: 0.35 U-value	5.11	0.21	(4%)	6,038	52	(1%)
Window: 0.30 SHGC	5.07	0.25	(5%)	5,277	813	(13%)
Window: 0.35 U-value and 0.35 SHGC	5.05	0.27	(5%)	5,657	433	(7%)
Window: 0.30 U-value and 0.30 SHGC	4.87	0.45	(8%)	5,252	838	(14%)
Air conditioner: 11 SEER	4.96	0.36	(7%)	5,568	522	(9%)
Air conditioner: 12 SEER	4.66	0.66	(12%)	5,130	960	(16%)
Air conditioner: 13 SEER	4.41	0.91	(17%)	4,763	1327	(22%)
Air conditioner: 14 SEER	4.19	1.13	(21%)	4,447	1643	(27%)

It can be seen that the various upgrades have different impacts on the peak demand and electricity consumption. The greatest impacts came from air conditioner upgrades (especially at higher SEERs), substantially improved windows, and reduced infiltration. The benefit from window upgrades is less than might be normally expected in a hot climate and is attributable to the base cases complying with the IECC, which has stringent window requirements. Increased attic insulation and wall insulation have low peak demand benefits, but are still common upgrades because they improve occupant comfort.

Step 3: Assess Upgrade Package

In Step 2 the peak demand and electricity consumption savings were estimated for various individual upgrades. In this step the synergistic effects of multiple upgrades are assessed by creating a package that includes several individual upgrades. The characteristics of this package are shown in Exhibit 5. The upgrades that were chosen represent appropriate energy-efficiency practices for Houston, Texas.

Exhibit 5. Upgrade Package Components

Upgrade Type	Base Case	Upgrade
Thermal	R-11 wall ins.	R-13 wall ins.
	R-22 attic ins.	R-30 attic ins.
HVAC system	10 SEER	12 SEER
Window	0.47 U-value 0.40 SHGC	0.35 U-value 0.35 SHGC
Infiltration	0.46 nac/h	0.35 nac/h

This upgrade package was modeled in DOE-2 for each of the 432 home configurations and the results are shown in Exhibit 6.

Exhibit 6. Average Demand and Energy Impacts of Upgrade Package

Scenario	Peak Demand (kW)			Electricity Consumption (kWh/year)		
	Average	Average Savings from Base Case		Average	Average Savings from Base Case	
Base case	5.32	-		6,090	-	
R-13 wall	5.26	0.06	(1%)	6,024	66	(1%)
R-30 attic	5.30	0.02	(0.4%)	6,058	32	(0.5%)
0.35 nac/h	4.97	0.35	(7%)	5,828	262	(4%)
0.35 U-value 0.35 SHGC	5.05	0.27	(5%)	5,657	433	(7%)
12 SEER	4.66	0.66	(12%)	5130	960	(16%)
Total of individual upgrades	-	1.36	(26%)	-	1,687	(28%)
Package of upgrades	4.09	1.23	(23%)	4,424	1,666	(27%)

The average demand savings achieved by the homes with the upgrade package is 23% while the average electricity consumption savings is 27%. The upgrade package savings (1.23 kW; 1,666 kWh) are slightly less than the sum of the savings from the individual upgrades (1.36 kW; 1,687 kWh). This is due to an overlap in the impact of the individual measures. A significant benefit of combining these upgrades that is not recognized in Exhibit 6 is the ability to downsize the air conditioning equipment. This can result in substantial dollar savings.

Step 4: Conduct Sensitivity Analysis

In Step 1 it was demonstrated that there can be substantial variation in the peak demand between homes and that these variations are due to the changes in house characteristics. In order to better understand how certain house characteristics can impact the potential for peak demand savings, a sensitivity analysis was conducted on the package of upgrades defined in Step 3. This was done by grouping the results according to the different characteristics and comparing the average peak demand and electricity consumption of these groupings. For example, the peak demands for all of the single story homes were averaged, as were the peak demands for all the double story homes. These two averages were then compared to each other. The results show, on average, what the peak demand of a single story home is in comparison with a double story home for the upgrade package. Exhibit 7 presents this and other comparisons to provide insight into the effect house characteristics have on peak demand savings.

Exhibit 7. Sensitivity of Peak Demand and Electricity Consumption to House Characteristics

Home Characteristic	Variations	Base Case		Package of Upgrades		Savings Due to Upgrade	
		Average Peak Demand (kW)	Average Electricity Consumption (kWh/yr)	Average Peak Demand (kW)	Average Electricity Consumption (kWh/yr)	Average Peak Demand (kW)	Average Electricity Consumption (kWh/yr)
Area per floor (sq ft /floor)[4]	1,250	3.84	4,436	3.00	3,243	0.84	1,193
	1,750	5.02	5,742	3.86	4,170	1.16	1,572
	2,500	6.70	7,645	5.12	5,540	1.58	2,105
Total home size (sq ft)[4]	1,250	2.76	3,181	2.18	2,328	0.58	853
	1,750	3.53	4,018	2.74	2,925	0.79	1,093
	2,500	4.77	5,466	3.70	3,980	1.07	1,486
	3,500	6.52	7,466	4.98	5,415	1.54	2,051
	5,000	8.79	10,049	6.66	7,274	2.13	2,775
Number of stories[4]	1-story	3.63	4,146	2.83	3,019	0.80	1,127
	2-story	6.74	7,736	5.15	5,615	1.59	2,121
Foundation type	Slab-on-grade	5.29	5,858	4.09	4,186	1.20	1,672
	Crawl-space	5.35	6,321	4.10	4,662	1.25	1,659
House orientation	North	4.94	5,466	3.73	3,926	1.21	1,540
	East	5.30	6,281	4.12	4,586	1.18	1,695
	South	5.19	6,055	4.10	4,456	1.09	1,599
	West	5.85	6,555	4.42	4,727	1.43	1,828
Window percent	15% WFA	5.09	5,522	3.96	4,014	1.13	1,508
	18% WFA	5.32	6,085	4.09	4,423	1.23	1,662
	21% WFA	5.55	6,662	4.22	4,830	1.33	1,832
Roof solar absorptivity	0.35	5.27	5,903	4.06	4,294	1.21	1,609
	0.75	5.34	6,140	4.10	4,458	1.24	1,682
	0.90	5.36	6,225	4.11	4,519	1.25	1,706

[4] The results for this house characteristic are based on a straight average and are not weighted based on the distribution of new home size.

Exhibit 7 shows that several housing characteristics can have a significant impact on peak demand savings. This was most noticeable for total home size, area per floor, and number of stories. All three characteristics indicate that the larger the home, the larger the potential for peak demand savings. The remaining housing characteristics, when varied, had surprisingly little effect on peak demand savings. For example, the difference between houses with crawl spaces and slab on grades was only 0.05 kW on average. This could be due to the way the crawl spaces were modeled or it could indicate a weakness in the DOE-2 ground-modeling algorithm. One of the most unexpected results was for roof solar absorptivity. Various studies have found that the color of materials used on the roof can considerably affect the peak demand savings for a home. It was anticipated that a low solar absorptivity (e.g., cool roof) would lower a home's demand. While this trend does occur, the average peak demand difference between a cool roof and a standard roof is not significant (i.e., 0.09 kW on average for the base case). An investigation into this discrepancy suggests that the reduced impact is likely the result of three factors: 1) how DOE-2 reports peak loads, 2) the impact of using TMY2 weather data, and 3) the inadequacy of DOE-2 to model the behavior of the air-handler unit in unconditioned spaces. The first two issues were discussed in the beginning of the Methodology and Results section. The third issue is due to the fact that DOE-2 only models duct air leakage as a supply loss, i.e., the supply ducts leak conditioned air to the unconditioned space but the return ducts do not "suck" in hot unconditioned air. The return "leakage" is likely to have a more significant impact on the home's peak demand. Preliminary testing of other energy modeling programs indicates comparable demand differences due to changing roof solar absorptivity.

The peak demand and electricity consumption savings of homes are also impacted by characteristics not presented in Exhibit 7. Included are the specifications (or lack there of) in the energy code that is used in defining the base case scenario(s). Demand and electricity consumption savings due to energy efficiency upgrades will be smaller for base case scenarios defined with a more stringent versus a less stringent energy code. Throughout this analysis the base case scenarios were designed to the 2000 IECC since it is the energy code that was recently adopted in Texas. If another energy code had been used, the base case demand and electricity consumption, and corresponding upgrade savings, would have been different. Exhibit 8 compares the average peak demand and electricity consumption of base case scenarios that are designed to the 1993 Model Energy Code (MEC) versus the 2000 IECC.

Exhibit 8. Comparison of Homes Compliant with Different Building Codes

Building Code Used in Base Case Scenarios	Peak Demand (kW)	Electricity Consumption (kWh/year)
1993 MEC	6.86	9,855
2000 IECC	5.32	6,090

The primary differences between these two codes, from an energy and demand perspective, are the more stringent window and thermostat requirements in the 2000 IECC. A detailed description of the differences between these codes can be found in "Principle Technical Differences Between the HERS Reference Home and the Chapter 4, IECC (including the 2002 supplement) Standard Design Home," by Philip Fairey. As shown in Exhibit 8, the difference in average peak demand and electricity consumption for the base case homes can be fairly significant.

Step 5: Evaluated Programmatic Impacts

Planners and utilities are not only interested in the per home impact of energy efficiency programs, but also in the impact that a number of homes would have when upgraded within a community. To estimate the programmatic impact of an energy efficiency program, three levels of implementation (e.g., community penetration) were assumed - 100, 500, and 1,000 homes. The results of the upgrade package defined in Step 3 were multiplied by these levels of implementation (number of homes upgraded) and the peak demand reduction, electricity consumption reduction, and emissions reductions[5] were assessed. These results are presented in Exhibit 9.

[5] Emission factors were taken from the EPA's Emissions & Generation Resource Integrated Database (E-Grid) using emission factors for Reliant HL&P 1998 (the latest emission factors available).

Exhibit 9. Estimated Program Impacts of Implementing an Energy Efficiency Upgrade Package

Number of Homes Upgraded	Avoided Peak Demand (kW)	Avoided Electricity Consumption (MWh/yr)	Avoided Pollution (lbs/year)		
			CO_2	NO_x	SO_X
1	1.23	1.6	2,187	4	5
100	123	167	218,746	400	473
500	615	833	1,093,729	1,999	2,366
1,000	1,230	1,666	2,187,458	3,998	4,731

Note: The weighted averageS of all homes modeled are used and therefore the results do not represent any single home type or size.

This exhibit demonstrates that significant benefits, including avoided peak demand and atmospheric pollution, can be realized from implementing an energy efficiency program.

CONCLUSIONS AND NEXT STEPS

The purpose of this analysis was to better understand the relationship between energy efficiency upgrades and peak demand reduction. Over 6,000 homes were modeled in DOE-2, taking into account the wide variation of characteristics (size, orientation, foundation, etc.) that occurs in housing stock. This analysis revealed that there are three driving factors in determining the effect that energy efficiency upgrades will have on demand: 1) the energy characteristics (e.g., insulation R-value, equipment efficiency, etc.) of the base case or reference point from which the comparison will be made; 2) the type and measure of upgrades; and 3) the architectural characteristics of the home (e.g., floor area, number of stories, etc.).

It was demonstrated that the effects of energy efficiency upgrades depend considerably on the energy characteristics of the base case homes. For example, window upgrades will have less of an impact on a base home that has efficient windows to begin with (e.g., the window differences as prescribed in the 2000 IECC versus the 1993 MEC.) This conclusion is significant, because as state energy codes change, so will the relative impacts of energy efficiency upgrades. The second factor that had a major influence on a home's energy and demand savings was the specific upgrade measures that were selected. It was found that greatest energy and demand savings were attributed to higher efficiency air-conditioners, reduced house infiltration, and higher performing windows. The third driving factor in the effectiveness of energy-efficiency upgrades on reducing peak demand is the architectural characteristics of a home. Though a number of architectural characteristic variations were modeled, it was found that the primary drivers consistently related to the size of the home (e.g., area per floor, total home size, and number of stories).

Understanding the effect that each of these driving factors has on the effectiveness of upgrades can better equip utilities and planners to design and implement energy-efficiency programs. This paper demonstrated that a package of upgrades implemented on a community scale, could save as much as 1.2 MW of demand and 1,666 MWh of energy for every 1,000 homes.

Next steps

This paper primarily analyzed the demand savings attributed to a reduction in a home's air conditioning load. Next steps should include evaluating the demand impacts of reducing additional end-use loads. These analyses should include upgrades in electric space and water heating, as well as lighting and appliances. In addition, other variables that could affect peak demand savings should be evaluated including the impact of occupant behavior and climatic changes. Finally, it is recommended that a more detailed analysis be conducted on how energy software models the impact of cool roofs on a home's electric demand and consumption.

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Homes produced with airtight duct systems (around 15% savings in Htg and Cooling Energy)

Palm Harbor Homes	22,000
Southern Energy Homes	8,000
Cavalier Homes	1,000
	= = =
Subtotal	31,000

Technical measures incorporated in BAIHP homes include some or many of the following features - better insulated envelopes (including Structural Insulated Panels and Insulated Concrete Forms), unvented attics, “cool” roofs, advanced air distribution systems, interior duct systems, fan integrated positive pressure dehumidified air ventilation in hot humid climates, quiet exhaust fan ventilation in cool climates, solar water heaters, heat pump water heaters, high efficiency right sized heating/cooling equipment, and gas fired combo space/water heating systems.

HOMES BY THE FLORIDA HOME ENERGY AND RESOURCES ORGANIZATION (FL.H.E.R.O.)

Over 400 single and multifamily homes have been constructed in the Gainesville, FL area with technical assistance from FL H.E.R.O. These homes were constructed by over a dozen different builders. In this paper data from 310 of these homes is presented. These homes have featured better envelopes and windows, interior and/or duct systems with adequate returns, fan integrated positive pressure dehumidified air ventilation, high efficiency right sized heating/cooling equipment, and gas fired combo space/water heating systems. The innovative outside air (OA) system is described below.

The OA duct is located in the back porch (Figure 1) or in the soffit (Figure 2). The OA is filtered through a 12"x12" filter (which is readily available) located in a grill (Figure 3) which is attached to the OA duct box. The flex OA duct size varies depending on the system size - 4" for up to 2.5 tons, 5" for 3 to 4 ton and 6" for a 5 ton system. The OA duct terminates in the return air plenum after a manually adjustable butterfly damper (Figure 4).

Figure 1 OA Intake Duct in Back Porch

Figure 2 OA Intake Duct in Soffit

Figure 3 Filter Backed Grill Covering the OA Intake

Figure 4 Butterfly Damper for OA control

The damper can be set during commissioning and closed by the homeowner in case the OA quality is poor (e.g. forest fire). This system introduces filtered and conditioned ventilation air only when the cooling or heating system is operational. The ventilation air also positively pressurizes the house. Data on the amount of ventilation air or positive pressurization is not available from a large sample of homes. A few measurements indicate that about 25 to 45 cfm of ventilation air is provided which pressurizes the house in the range of +0.2 to +0.4 pascals.

Measured Home Energy Ratings (HERS) and airtightness on these FL. H.E.R.O. homes is presented next in figures 5 through 8. Data is presented for both single family detached (SF) and multifamily homes (MF). See Table 2 below.

Table 2. Summary statistics on FL.H.E.R.O. Homes
n = sample size

	SF	MF
Median cond area	1,909	970
% constructed with 2x4 frame or frame and block	94%	100%
Avg. Conditioned Area, ft^2	1,993 (n=164)	1,184 (n=146)
Avg. HERS score	87.0 (n=164)	88.0 (n=146)
Avg. ACH50	4.5 (n=164)	5.2 (n=146)
Avg. Qtot (CFM25 as %of floor area)	6.9% (n=25)	5.0% (n=72)
Avg. Qout (CFM25 as %of floor area)	3.0% (n=15)	1.4% (n=4)

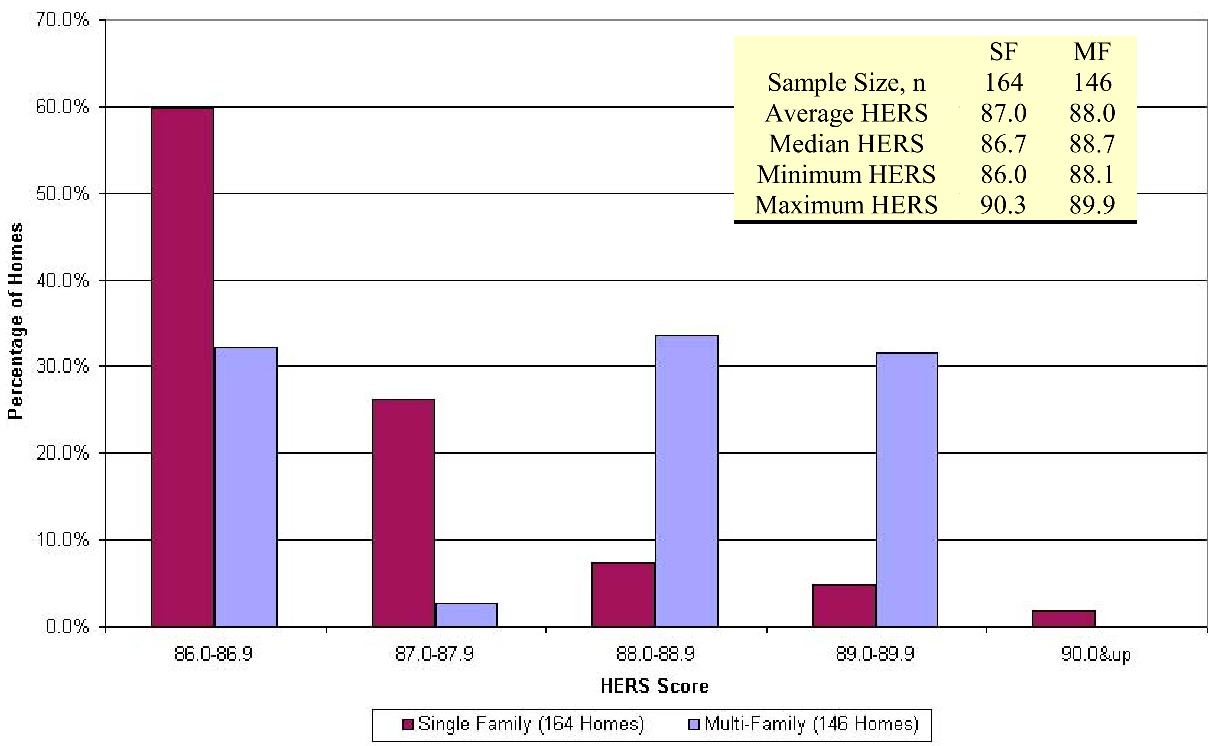

Figure 5 HERS Scores for FL H.E.R.O. Homes

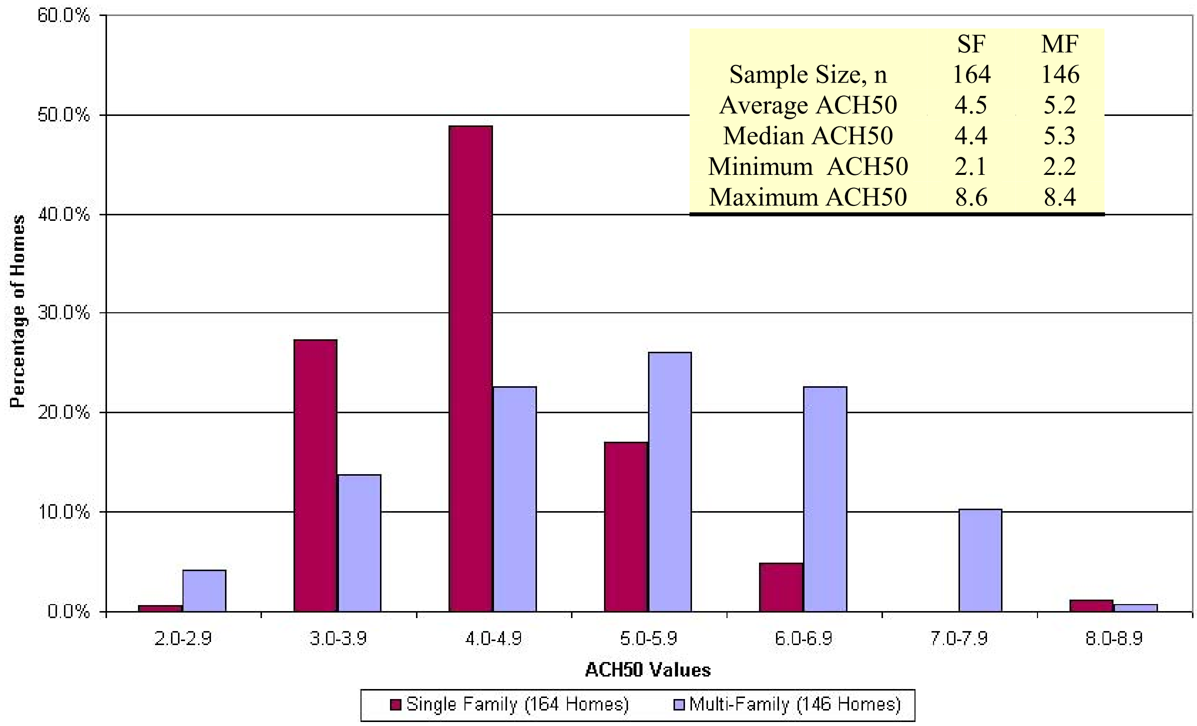

Figure 6 ACH50 Values for FL H.E.R.O. Homes

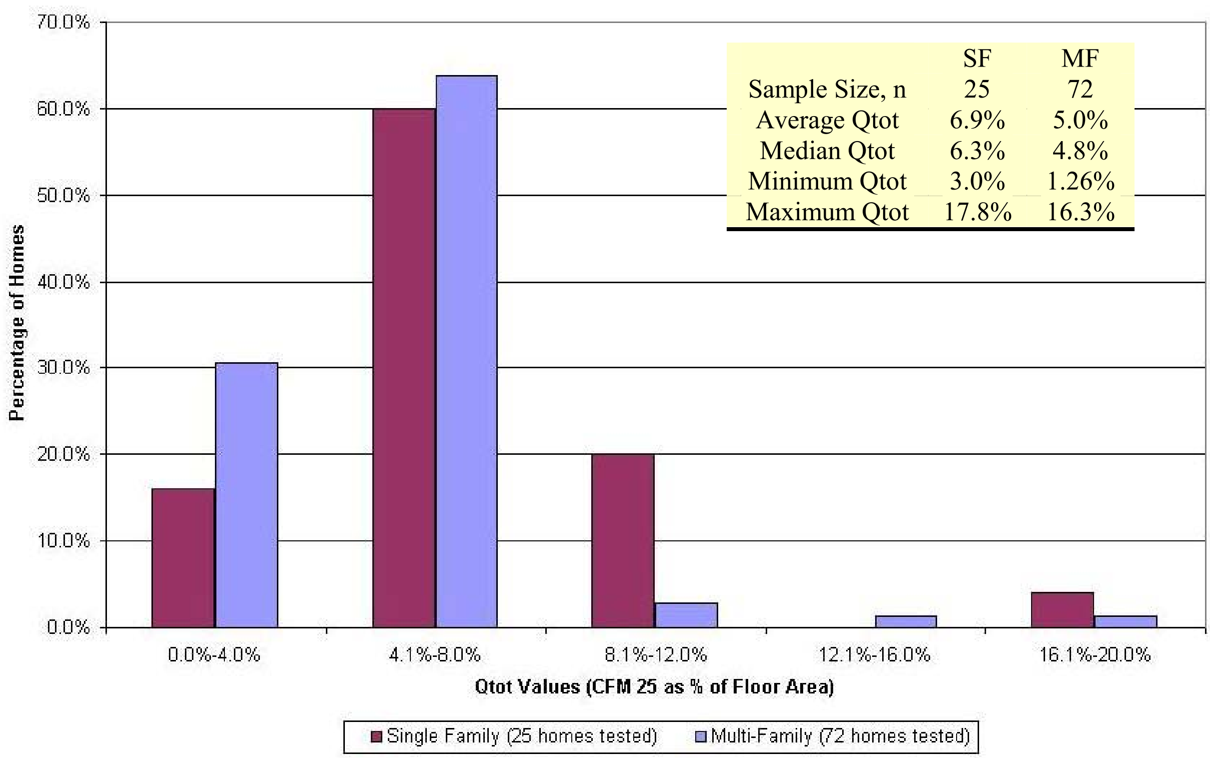

Figure 7 Qtot Values for FL H.E.R.O. Homes

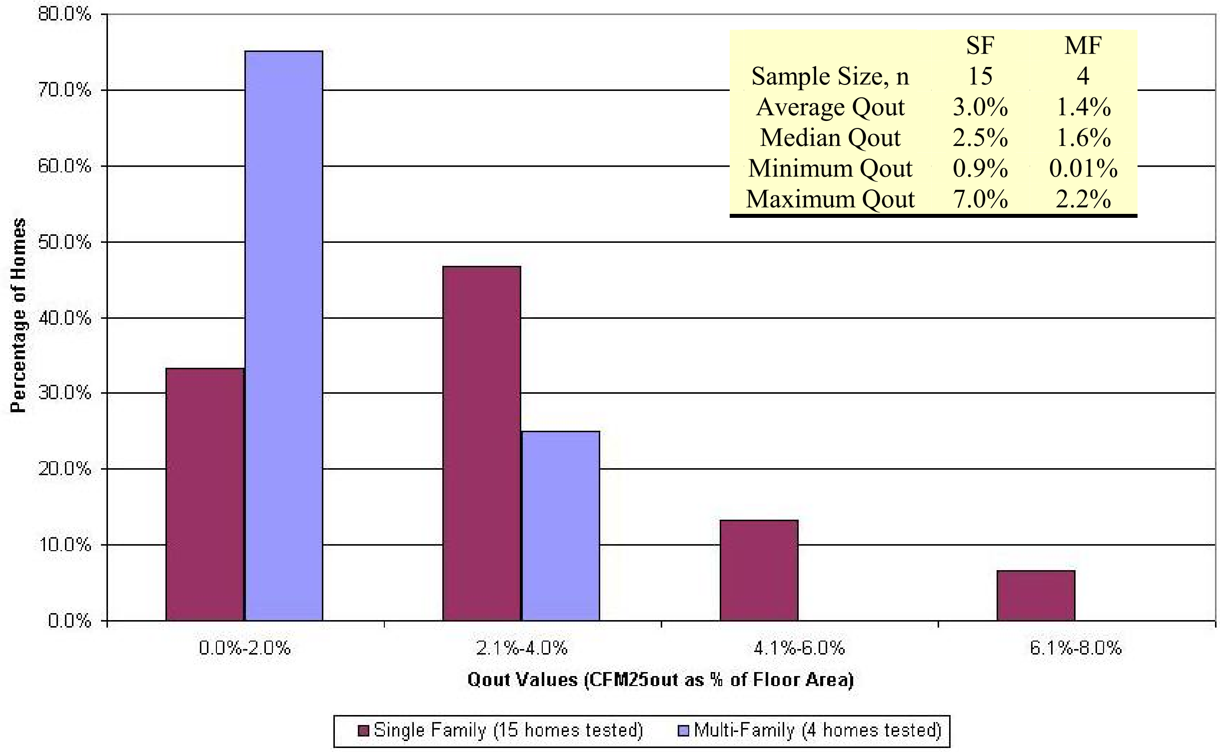

Figure 8 Qout Values for FL H.E.R.O. Homes

Data is available for other typical non BAIHP, new Florida homes (FPL , 1995 and Cummings et al, 2001). The FPL study had a sample size of over 300 single family homes and the median Qout was 7.5% , three times that of the FL. H.E.R.O. homes. In the Cummings study of 11 homes the measured average values were : ACH50= 5.7, Qtot=9.4% and Qout=4.7%. Although the sample sizes are small the FL. H.E.R.O. homes appear to have significantly more airtight duct systems than typical homes.

The remainder of the paper presents status of other tasks of the BAIHP project.

OTHER BAIHP TASKS

Moisture Problems in HUD code homes

The BAIHP team expends considerable effort working to solve moisture problems in existing manufactured homes in the hot, humid Southeast.

Some manufactured homes in Florida and the Gulfcoast have experienced soft walls, buckled floors, mold, water in light fixtures and related problems. According to the Manufactured Housing Research Alliance (MHRA), who we collaborate with, moisture problems are the highest priority research project for the industry.

The BAIHP team has conducted diagnostic tests (blower door, duct blaster, pressure mapping, moisture meter readings) on about 40 such problem homes from five manufacturers in the past two years and shared the results with MHRA. These homes were newly built (generally less than 3 years old) and in some cases just a few months old when the problems appeared. The most frequent causes were:

- Leaky supply ducts and/or inadequate return air pathways resulting in long term negative pressures.
- Inadequate moisture removal from oversized a/c systems and/or clogged condensate drain, and/or continuous running of the air handler fan.
- Presence of vinyl covered wallboard or flooring on which moist air condenses creating mold, buckling, soft walls etc.
- Low cooling thermostat set point (68-75F), below the ambient dew point.
- Tears in the belly board and/or poor site drainage and/or poor crawlspace ventilation creating high rates of moisture diffusion to the floor.

Note that these homes typically experience very high cooling bills as the homeowners try to compensate for the moisture problems by lowering the thermostat setpoints. These findings have been reported in a peer reviewed paper presented at the ASHRAE IAQ 2001. conference (Moyer et al)

The Good News:

As a result of our recommendations and hands-on training, BAIHP partner Palm Harbor Homes (PHH) has transformed duct design and construction practices in all of its 15 factories nationwide producing about 11,000 homes/yr. All Palm Harbor Home duct systems are now constructed with mastic to nearly eliminate air leakage and produced with return air pathways for a total cost of <$10/home!! The PHH factory in AL which had a high number of homes with moisture problems has not had a single problem home the past year!

Field Monitoring

Several houses and portable classrooms are being monitored and the data displayed on the web. (Visit http://www.infomonitors.com/). Of special interest is the side-by-side monitoring of two manufactured homes on the campus of the North Carolina A & T U. where the advanced home is saving about 70% in heating energy and nearly 40% in cooling energy, proving that the Building America goal can be met in manufactured housing. Other monitored sites include the Washington State U. Energy House in Olympia, WA; the Hoak residence in Orlando, FL; two portable classrooms in Marysville, WA; a classroom each in Boise, ID and Portland, OR. See other papers being presented at this symposium for details on two recently completed projects giving results from duct repairs in manufactured homes (Withers et al) and side by side monitoring of insulated concrete form and base case homes (Chasar et al).

“Cool” Roofs and Unvented Attics

Seven side-by-side Habitat homes in Ft. Myers, FL. were tested under unoccupied conditions to examine the effects of alternative roofing strategies. After normalizing the data to account for occupancy and minor differences in thermostat set points and equipment efficiencies, the sealed attic saved 9% and the white roofs saved about 20% cooling energy compared to the base case house with a dark shingle roof for the summer season in South Florida. Visit http://www.fsec.ucf.edu/%7Ebdac/pubs/coolroof/exsum.htm for more information.

Habitat for Humanity

Habitat for Humanity affiliates work in the local community to raise capital and recruit volunteers. The volunteers build affordable housing for and with buyers who can't qualify for conventional loans but do meet certain income guidelines. For some affiliates, reducing utility costs has become part of the affordability definition.

To help affiliates make decisions about what will be cost effective for their climate, BAIHP researchers have developed examples of Energy Star homes for more than a dozen different locations. These are available on the web at http://www.fsec.ucf.edu/bldg/baihp/casestud/hfh_estar/index.htm . The characteristics of the homes were developed in conjunction with Habitat for Humanity International (HFHI), as well as Executive Directors and Construction Managers from many affiliates. Work is continuing with HFHI to respond to affiliates requesting a home energy rating through an Energy and Environmental Practices Survey. 36 affiliates have been contacted and home energy ratings are being arranged using combinations of local raters, Building America staff, and HFHI staff.

HFHI has posted the examples of Energy Star Habitat homes on the internal web site PartnerNet which is available to affiliates nationwide.

“Green” Housing

A point based standard for constructing green homes in Florida has been developed and may be viewed at http://www.floridagreenbuildings.org/. The first community of 270 homes incorporating these principles is now under construction in Gainesville, FL. The first home constructed and certified according to these standards has won an NAHB energy award.

BAIHP researchers are participating as building science - sustainable products advisor to the HUD Hope VI project in Miami, redeveloping an inner city area with over 500 units of new affordable and energy efficient housing.

Healthy Housing

BAIHP researchers are participating in the development of national technical and program standards for healthy housing being developed by the American Lung Association.

A 50-year-old house in Orlando is being remodeled to include energy efficient and healthy features as a demonstration project.

EnergyGauge USA®

This FSEC developed software uses the hourly DOE 2.1E engine with FSEC enhancements and a user-friendly front end to accurately calculate home energy ratings and energy performance. This software is now available. Please visit http://energygauge.com/ for more information.

Industrial Engineering Applications

The UCF Industrial Engineering (UCFIE) team supported the development and ongoing research of the Quality Modular Building Task Force organized by the Hickory consortium, which includes thirteen of the nation's largest modular homebuilders. UCFIE led in research efforts involving factory design, quality systems and set & finish processes. UCFIE used research findings to assist in the analysis and design of two new modular housing factories – Excel homes, Liverpool, PA and Cardinal Homes - Wyliesburg, VA.

CONCLUSIONS

The entire BAIHP team of over 20 researchers and students are involved in a wide variety of activities to enhance the energy efficiency, indoor air quality and durability of new housing and portable classrooms.

In addition to energy efficiency, durability, health, comfort and safety BAIHP builders typically consider resource and water efficiency. For example, in Gainesville, FL BAIHP builders have incorporated the following features in developments:

- Better planned communities
- More attention given to preserving the natural environment
- Use of reclaimed sewage water for landscaping
- Use of native plants that require less water
- Storm water percolating basins to recharge the ground water
- Designated recreational areas
- Better designed and built infrastructure
- Energy efficient direct vented gas fireplaces (not smoke producing wood)

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